Chin. J. Astron. Astrophys. Vol. 6 (2006), No. 6, 655–662
(*http://www.chjaa.org*)

Chinese Journal of
Astronomy and
Astrophysics

Do Radio-loud Active Galactic Nuclei really follow the same $M_{\rm BH}$–σ_* Relation as Normal Galaxies? *

Yi Liu[1,2] and Dong-Rong Jiang[1]

[1] Shanghai Astronomical Observatory, Chinese Academy of Sciences, Shanghai 200030; *yliu@shao.ac.cn*
[2] Graduate School of Chinese Academy of Sciences, Beijing 100049

Received 2006 March 15; accepted 2006 April 29

Abstract In an examination of the relationship between the black hole mass $M_{\rm BH}$ and stellar velocity dispersion σ_* in radio-loud active galactic nuclei (AGNs), we studied two effects which may cause uncertainties in the black hole mass estimates of radio-loud AGNs: the relativistic beaming effect on the observed optical continuum radiation and the orientation effect on the broad emission line width. After correcting these two effects, we re-examined the $M_{\rm BH}$– $\sigma_{\rm [OIII]}$ relation for a sample of radio-loud and radio-quiet AGNs, and found the relation for radio-loud AGNs still deviated from that for nearby normal galaxies and radio-quiet AGNs. We also found there is no significant correlation between radio jet power and narrow [OIII] line width, indicating absence of strong interaction between radio jet and narrow line region. It may be that the deviation of the $M_{\rm BH}$– σ_* relation of radio-loud AGNs is intrinsic, or that the [OIII] line width is not a good indicator of σ_* for radio-loud AGNs.

Key words: black hole physics — galaxies: active — galaxies: nuclei — quasars: general

1 INTRODUCTION

There is abundant evidence which shows the evolution of black holes is closely coupled to that of their host galaxies. Kormendy & Richstone (1995) and Magorrian et al. (1998) showed that the central black hole mass correlates with the bulge mass and luminosity. The stellar velocity dispersion σ_* in the galactic bulge also relates to the mass of the center black hole (the $M_{\rm BH}$–σ_* relation). Gebhardt et al. (2000a) and Ferrarese & Merritt (2000) found the $M_{\rm BH}$ and σ_* correlation to be strong, suggesting a link between the formation of the bulge and the black hole. After investigating 31 nearby inactive galaxies, Tremaine et al. (2002) presented the relation as:

$$M_{\rm BH} = 10^{8.13}[\sigma_*/(200\,{\rm km\,s^{-1}})]^{4.02} M_\odot. \tag{1}$$

However, the bulge stellar velocity dispersion σ_* in the QSO is generally difficult to measure directly. Nelson & Whittle (1995,1996) made a comparison of bulge magnitudes, [OIII] line widths and σ_* in Seyfert galaxies, and found a good statistical relation between σ_* and $\sigma_{\rm [OIII]}$ ($\sigma_{\rm [OIII]} = {\rm FWHM([OIII])}/2.35$). The above relationship for normal galaxies also holds for active galaxies (Gebhardt et al. 2000b; Ferrarese et al. 2001; Wang & Lu 2001; Boroson 2003; Shields et al. 2003): the $M_{\rm BH}$–$\sigma_{\rm [OIII]}$ relation for all their radio-quiet sources follows that derived for nearby normal galaxies. It provides us a method to calculate the mass of black holes different from that in Kaspi et al. (2000) based on active galactic nuclei broad emission line width and continuum luminosity.

However, Bian & Zhao (2004) found that the relationship between the black hole mass and stellar velocity dispersion for narrow line Seyfert1s and radio-loud AGNs deviates from that for radio-quiet AGNs and

---

* Supported by the National Natural Science Foundation of China.

nearby normal galaxies. They suggested that the deviation in radio-loud AGNs might be due to measuring uncertainties of $\sigma_{[\rm OIII]}$ or $M_{\rm BH}$. Bonning et al. (2005) tested the use of [OIII] line widths as a surrogate for σ_* by studying the $M_{\rm HOST}$–$\sigma_{[\rm OIII]}$ relation in a sample of quasars for which the host galaxy luminosity has been measured. They found an increase of $\sigma_{[\rm OIII]}$ with σ_* when a wider range of measured or inferred σ_* is covered, although the radio-loud AGNs have $\sigma_{[\rm OIII]}$ smaller by 0.1 dex than radio-quiet QSOs of similar $L_{\rm HOST}$. Greene & Ho (2005) compared σ_* with the widths of several narrow emission lines in a sample of narrow-line Seyfert galaxies from Sloan Digital Sky Survey (SDSS) and found that $\sigma_{[\rm OIII]}$ exceeds σ_* by about 0.13 dex. However, Salviander et al. (2006) found that $\sigma_{[\rm OIII]}$ agrees with $\sigma_{[\rm OII]}$ well in their sample of SDSS QSOs. Bian, Yuan & Zhao (2005) investigated the radial velocity difference between the narrow emission-line components of [OIII] in a sample of 150 SDSS NLS1 galaxies, and found that the profile of [OIII] indicated two kinematically and physically distinct regions. The [OIII] line width depends not only on the bulge stellar gravitational potential, but also on the central black hole potential. Moreover, interaction between the radio jets and the narrow line region (NLR), or radio jets inspired star formation might also influence the physics hence the intensity and width of the [OIII] line.

Kaspi et al. (2000) derived an empirical correlation between the broad line region (BLR) size and the optical continuum luminosity at 5100 Å using the reverberation mapping technique. The empirical relationship has been frequently adopted to estimate the BLR size and then to derive the black hole mass in AGN samples. However, the relativistic jets of radio-loud AGNs both dominate the radio radiation and contribute significantly to the optical luminosity. The black hole mass in radio-loud AGNs would be overestimated if we use the empirical relationship between the BLR size and optical luminosity at 5100 Å obtained from the sample of radio-quiet AGNs (Kaspi et al. 2000). On the other hand, as the jet axis is close to the line of sight for radio-loud AGNs, the geometrical effects might affect the observed widths of the broad Hβ emission line and hence the black hole masses in radio-loud AGNs. These uncertainties in black hole mass calculation could affect the $M_{\rm BH}$–$\sigma_{[\rm OIII]}$ relation for radio-loud AGNs. In order to eliminating the beaming effect in the optical continuum radiation of radio-loud AGNs, Wu et al. (2004) provided a method to calculate the black hole mass by a tight empirical relationship between the BLR size and the Hβ emission line luminosity. In this paper, we re-assess the $M_{\rm BH}$–$\sigma_{[\rm OIII]}$ relation for a sample of radio-loud and radio-quiet AGNs after correcting the uncertainty in the black hole mass, and then examine whether the $\sigma_{[\rm OIII]}$ traces the σ_* in radio-loud AGNs. The relationship between the radio jet power and the [OIII] line width will also be investigated. We used a cosmology with $H_0 = 70\ {\rm km\ s^{-1}\ Mpc^{-1}}$, $\Omega_M = 0.3$, $\Omega_\Lambda = 0.7$. All values of luminosity used in this paper are corrected to our adopted cosmological parameters.

2 SAMPLE AND METHOD

We started this work with the sample of Xu et al. (1999) which has 409 sources from the literature or through the NASA Extragalactic Database (NED). To estimate the black hole mass and $\sigma_{[\rm OIII]}$, we searched the literature for all available full width at half maximum (FWHM) measurements of both the broad Hβ line and narrow $[{\rm OIII}]_{5007}$ line, as well as of the flux of broad Hβ emission line. Finally, we have a sample of 123 AGNs, with 25 flat-spectrum (FS) radio-loud AGNs, 35 steep-spectrum (SS) radio-loud AGNs and 63 radio-quiet (RQ) AGNs. The number of radio-loud AGNs in this sample is comparable to that in Bian & Zhao (2004).

Table 1 lists our sample with the relevant information (see *www.chjaa.org/2006_6_6.htm* for the full table). Columns (1)–(3) give the object's IAU name, its type (FS, SS or RQ) and redshift. Columns (4)–(6) list the black hole mass, the references for the adopted FWHM of broad Hβ emission line, and flux of broad line Hβ. Columns (7)–(8) list the $\sigma_{[\rm OIII]}$ and its references. More detailed description can be found in the table caption.

Through the reverberation mapping method, Kaspi et al. (2000) presented an empirical relation between the BLR size and the monochromatic luminosity at 5100 Å, and then the mass of the black hole can be estimated by using the formula $M_{\rm BH} = R_{\rm BLR} V^2 G^{-1}$. However, in radio-loud AGNs, there are two effects would cause uncertainties in the black hole mass estimate. First, the radio observations showed that the orientation of the jets in radio-loud AGNs, especially in flat spectrum radio-loud AGNs, is close to the line of sight. The synchrotron emission of the jet is then Doppler boosted, and the contribution of the synchronization emission at the optical band may dominate over the thermal emission from the disk. So the black hole mass in radio-loud AGNs could be overestimated. The second effect is this: if the BLR is

Table 1 $M_{\rm bh}$ and $\sigma_{\rm [OIII]}$ for Our Sample

Name (1)	Type (2)	z (3)	$M_{\rm BH}$ (4)	Refs. (5)	Refs. (6)	$\sigma_{\rm [OIII]}$ (7)	Refs. (8)
0003+15	SS	0.450	9.22	BG92	S81	2.17	H84
0003+19	RQ	0.026	7.51	S99	S81	2.08	W92a
0007+10	FS	0.089	8.93	B96	S81	2.12	D88
0026+12	RQ	0.142	8.05	BG92	S81	2.02	D88
0046+31	RQ	0.015	8.48	T95	S81	2.19	W92a
0049+17	RQ	0.064	8.27	BG92	BG92	2.42	S89b
...	...	...	...	...	...	...	...
1845+79	SS	0.056	8.97	L96	S81	2.64	L96

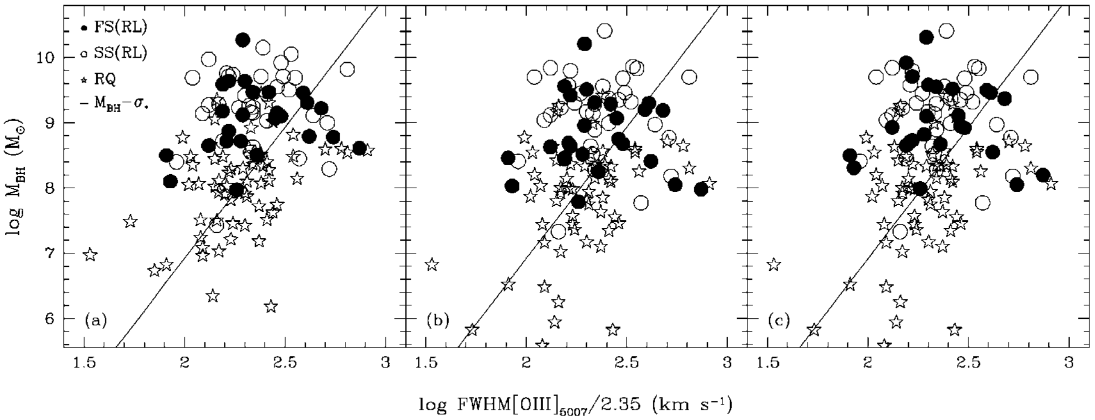

Fig. 1 Black hole mass versus $\sigma_{\rm OIII}$ plots. The black hole masses were derived from Hβ line widths. (a) without the orientation correction and from the optical continuum luminosity; (b) without the orientation correction and from the Hβ luminosity; (c) with corrections for both the Doppler beaming effect and orientation effect. Filled circles mark the flat spectrum radio-loud AGNs; open circles, the steep spectrum radio-loud AGNs and pentagons, the radio-quiet AGNs. The solid line is the $M_{\rm BH}$–σ_* relation from Eq. (1).

disk-like, the broad line width will depend on the orientation of the disk, and the broad line width of the radio-loud AGNs will be smaller than those in radio-quiet AGNs, even if they have similar black hole masses and BLR sizes (see Cao 2004; Xu & Cao 2006, for BL Lac objects). Wu et al. (2004) gave the relationship between the broad emission line Hβ luminosity and size of broad line region derived from the reverberation mapping method. Then the optical luminosity with the beaming effect eliminated can be calculated using the broad line emission luminosity. As for the orientation effect in the emission line width, Lacy et al. (2001) put forward using a factor $R_{\rm c}^{0.1}$ in all radio-loud AGNs ($R_{\rm c}$ is the ratio of the core to the extended radio luminosity in the rest frame of the sources) to correction this effect. However, the correction is invalid for sources with $0 < R_{\rm c} < 1$, so we only apply this correction for sources with $R_{\rm c} > 1$. After these two corrections, we calculated the black hole mass and compared the $M_{\rm BH}$–$\sigma_{\rm [OIII]}$ relations for radio-loud and radio-quiet AGNs. The results are plotted in Figure 1.

3 RESULTS AND DISCUSSION

In Figure 1(a)–(c) we plot the relation between $\sigma_{\rm [OIII]}$ and black hole mass $M_{\rm BH}$ obtained from various ways: in Figure 1(a), the black hole masses are estimated without any corrections; in Figure 1(b), with correction for the beaming effect but not for the orientation effect; in Figure 1(c), with corrections for both the beaming effect (for all radio-loud objects) and the orientation effect (for only flat spectrum radio-loud AGNs). The filled circles mark the flat spectrum radio-loud AGNs; the open circles, the steep spectrum radio-loud AGNs, and the stars, the radio-quiet AGNs. The solid lines in Figure 1(a)–(c) are the $M_{\rm BH}$–σ_* relation of Tremaine et al. (2002).

The beaming and orientation effects move the black hole mass in opposite directions. On the one hand, as with the radio luminosity, the optical luminosity of radio-loud quasars can also be contaminated by relativistically beamed jet emission. In fact, the optical emission of radio-loud quasars is a mixture of thermal and non-thermal emissions, and has a general tendency to be orientated with their jets beamed along our line of sight, although not in each individual case. Thus the black hole mass in radio-loud AGNs is reduced after correcting the beaming effect of the radio jet (Fig. 1(a) and 1(b)). On the other hand, if the geometry of the broad line region is disk-like, then the object has smallest line width when the jet axis is along the line of sight, and the correction for orientation effect will increase the black hole mass.

Figure 1(c) shows that the radio-quiet and radio-loud AGNs occupy two distinct regions in the $M_{\rm BH}$–$\sigma_{\rm [OIII]}$ plane. For the radio-quiet AGNs, the $M_{\rm BH}$–$\sigma_{\rm [OIII]}$ relationship we found is the same as the other authors; for the radio-loud AGNs, ours still deviates from the $M_{\rm BH}$–σ_* relation for nearby normal galaxies, even after eliminating the beaming effect and orientation effect in the black hole mass calculation. The black hole masses of radio-loud AGNs plotted in Figure 1(c) are calculated from the width of Hβ line and the luminosity of Hβ described in Section 2. The beaming and orientation effects are two factors causing uncertainties in the black hole masses. To eliminate contamination by the emission from the radio jets, continuum luminosity at 5100 Å was substituted for the broad line emission luminosity. However, for the radio-loud AGNs, the deviation of the $M_{\rm BH}$–σ_* relation remains after removing the orientation factor, but we must keep in mind that the relationship between the broad line region radii $R_{\rm BLR}$ and broad emission line luminosity $L_{\rm H\beta}$ which we used to calculate the black hole mass in our sample was derived from a sample of radio-quiet AGNs (Kaspi et al. 2000). A $R_{\rm BLR}$–$L_{5100\rm\AA}$ relation for radio-loud AGNs based on the reverberation mapping method is still unavailable so far. Thus we are not clear whether the relationships between $R_{\rm BLR}$ and $L_{5100\rm\AA}$ or $L_{\rm H\beta}$ are systematically different for radio-loud and radio-quiet AGNs. If they are different, then $R_{\rm BLR}$ will be one order of magnitude lower in radio-loud AGNs than in radio-quiet AGNs of similar optical/line luminosity, since the broad line width FWHM$_{\rm H\beta}$ is similar in both. Because there is so far no evidence for this kind of difference, we think the uncertainties in the black hole mass calculation may not be the main reason for the deviation in radio-loud AGNs.

Assuming radio-loud AGNs follow the same $M_{\rm BH}$–σ_* relation as nearby normal galaxies and radio-quiet AGNs, we can derive the [OIII] line width from the $M_{\rm BH}$–$\sigma_{\rm [OIII]}$ relation and then derive the deviation in the line, Δ[OIII]. Figures 2 and 3 present the number distributions of [OIII] line width and that of Δ[OIII] for radio-loud and radio-quiet AGNs, respectively. The median [OIII] line width is similar in these two sub-samples; being 510 $\rm km\ s^{-1}$ for radio-loud, and 480 $\rm km\ s^{-1}$ for radio-quiet AGNs. However, it is obvious that the observed [OIII] line widths in radio-loud AGNs are smaller than are expected from the $M_{\rm BH}$–σ_* relation for normal galaxies.

Although several research groups have investigated whether or not $\sigma_{\rm [OIII]}$ traces σ_*, the use of $\sigma_{\rm [OIII]}$ for σ_* is controversial. Outflow combined with extinction of the far side of the NLR could result in an asymmetrical non-Gaussian profile of the [OIII] emission line (Nelson & Whittle 1995). Other strong iron emission lines, like the FeII line located close to the [OIII] line, may mask the latter. There is some evidence suggesting that radio jets influence the physical and dynamical state of the NLR (de Bruyn & Wilson 1978; Ho & Peng 2001). Nelson & Whittle (1996) found that the strong radio sources have broader [OIII] line widths than weak radio sources. It seems that the jet plasma interacts with, and accelerates the NLR, thus boosting the line width. However, radio-loud QSOs on average have smaller [OIII] line widths than radio-quiet QSOs, as was found by Bonning et al. (2005). Smith et al. (1990) found there are no super-virial [OIII] line widths among objects with powerful kpc scale radio jets.

Radio jet power, as a fundamental radio parameter indicating the energy transported from the central engine through the radio jet, can be used to investigate the relationship between the radio jet and the narrow line regions. We used the formula derived from Punsly (2005):

$$Q_{\rm jet} = 5.7\times10^{44}(1+z)^{1+\alpha}Z^2F_{151}\ \ {\rm erg\,s^{-1}}, \tag{2}$$

$$Z \approx 3.31 - 3.65\times\left[(1+z)^4 - 0.203(1+z)^3 + 0.749(1+z)^2 + 0.444(1+z) + 0.205\right]^{-0.125}, \tag{3}$$

to estimate the jet power, where F_{151} is the optically thin flux density from the lobes measured at 151 MHz in units of Jy, and the value of $\alpha\approx1$ is suggested by the observations (Kellermann, Pauliny-Toth

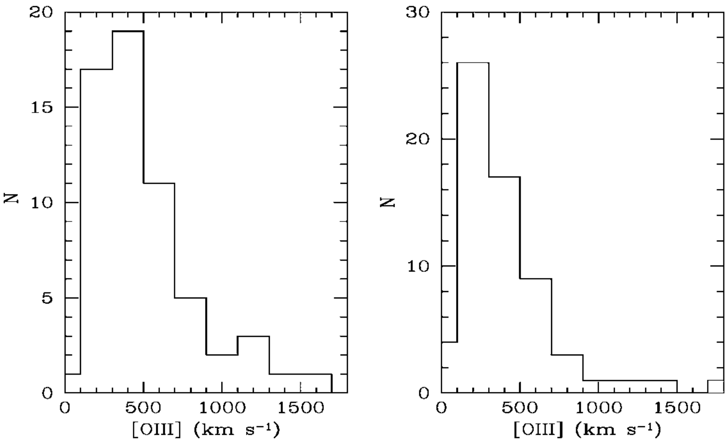

Fig. 2 Number distribution of observed [OIII] line widths for radio-loud AGNs (left) and radio-quiet AGNs (right).

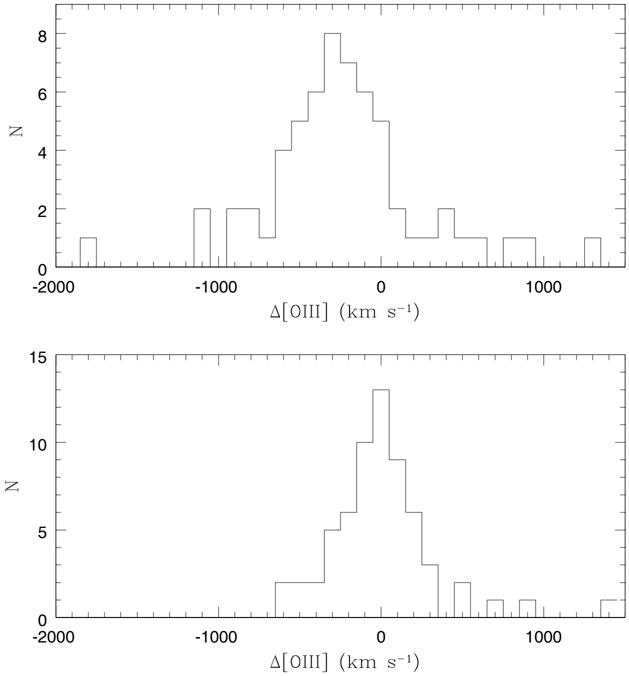

Fig. 3 Number distribution of differences between the observed [OIII] line widths and expected from $M_{\rm BH}$–σ_* relation for radio-loud AGNs (upper) and radio-quiet AGNs (lower).

& Williams 1969) as a good fiducial value (see Punsly 2005 for more details). We also estimated the jet power by substituting the extrapolated extended 151 MHz flux density ($\alpha = 1.0$), instead of the measured 151 MHz flux since the 151 MHz emission can be from radio cores with Doppler boosted effects (Liu, Jiang & Gu 2006). The relationship between the radio jet power and $\sigma_{\rm [OIII]}$ is shown in Figure 4, the filled circles denote all radio-loud AGNs in our sample, the open squares added on filled circles denote objects

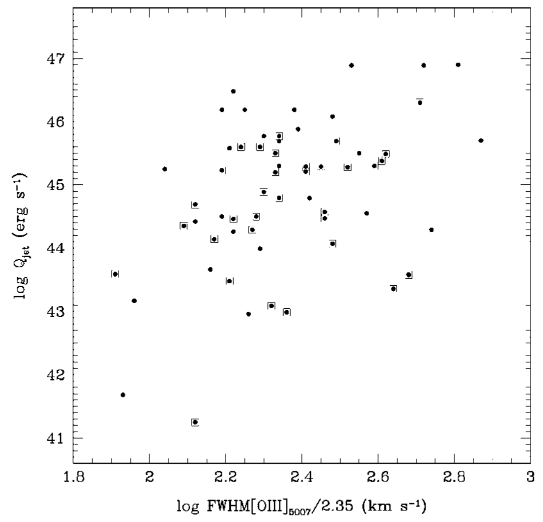

Fig. 4 Relationship between radio jet power and [OIII] line width for radio-loud AGNs. Squares added on filled circles mark out black hole masses in the range from $10^{8.5}M_\odot$ to $10^{9.5}M_\odot$.

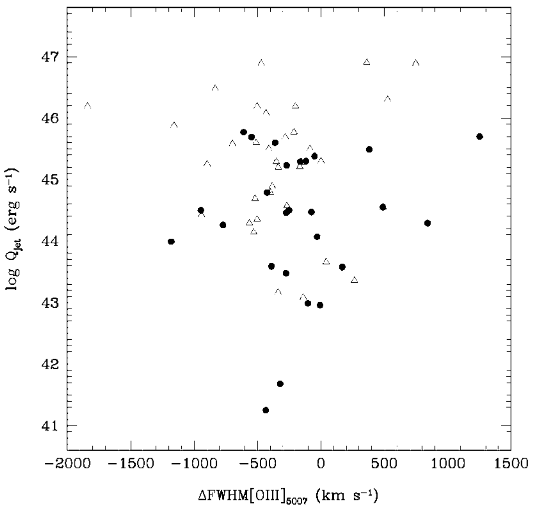

Fig. 5 Relationship between radio jet power and Δ[OIII] line width for radio-loud AGNs. Filled circles denote flat spectrum, and open triangles, steep spectrum sources.

with black hole masses ranging from $10^{8.5}M_\odot$ to $10^{9.5}M_\odot$. Using the Spearman rank correlation analysis, we find a significant correlation between radio jet power and [OIII] line width with a correlation coefficient of $r = 0.32$ at $\gg 99$ % confidence. It should be noted with caution that this correlation may be caused by their shared dependence on the black hole mass, so it may not be an intrinsic correlation. So we check the correlation between the Δ[OIII] line width and the radio jet power. Figure 5 plots Δ[OIII] versus radio jet power in our sample and it shows no significant correlation. It seems to support the scenario that there is no strong interaction between radio jet and the narrow line region. Moreover, we should be cautious with an interaction between radio jet and narrow line region: this effect may broaden the narrow line width, and the 'true' [OIII] width will be narrower than the observed width, leading to an increased offset in the $M_{\rm BH}$–$\sigma_{\rm [OIII]}$ relation of radio-loud AGNs. Greene & Ho (2005) found that the presence of core radio emission seems to have no impact on the observed [OIII] line width, and we find the same result with the radio jet power. However, Greene & Ho (2005) found that extended radio sources appear to have narrower line widths, as is found in our sample. Without knowing the offset in the $M_{\rm BH}$–$\sigma_{\rm [OIII]}$ relation, Bonning et al. (2005) pointed out that radio-loud AGNs have $\sigma_{\rm [OIII]}$ smaller by 0.1 dex than radio-quiet AGNs with similar $L_{\rm HOST}$, and the narrower $\sigma_{\rm [OIII]}$ for radio-loud AGNs is the main cause of this offset. However, in our whole sample, we found the median Δ[OIII] is about -300 km s^{-1}, that is, about 0.2 dex in narrow line [OIII] width for radio-loud AGNs compared to nearby normal galaxies. If the radio-loud AGNs follow the $M_{\rm BH}$–σ_* relation in nearby normal galaxies, then the real σ_* in radio-loud AGNs should be more than 0.2 dex larger than that inferred from the [OIII] width.

Our sample is simply compiled from the literature, so selection effects may have influenced the results. If the deviation in the $M_{\rm BH}$–$\sigma_{\rm [OIII]}$ relation of radio-loud AGNs was mainly caused by selection effects, then radio-loud AGNs with low black hole masses and large narrow line [OIII] width might have been missed out. However, Laor (2000) studied the black hole mass in the Palomar-Green quasar sample, and pointed out that nearly all PG quasars with $M_{\rm BH} > 10^9M_\odot$ are radio-loud, while quasars with $M_{\rm BH} < 3\times10^8M_\odot$ are practically all radio-quiet. Therefore, it is not possible that we have missed so many this kind radio-loud AGNs with low black hole masses and large narrow line [OIII] width during our sample collecting, so we think the deviation may not mainly be caused by selection effects in our sample. We need a complete matching sample including radio-loud and radio-quiet AGNs to carry out further studies on the influence of the selection effects.

The deviation of the $M_{\rm BH}$–σ_* relation of radio-loud AGNs cannot be explained by the beaming effect on the optical continuum luminosity, by the orientation effect on broad line region or by the interaction between radio jet and narrow line region. The redshift of all objects in our sample are less than 1.0 because of our requiring [OIII] and Hβ emission line at the same time. It is worth to extend the investigation of $M_{\rm BH}$–$\sigma_{\rm [OIII]}$ relation to higher redshifts to avoid the limitation in the sample selection. One possible reason is that the [OIII] line may not be a good indicator of stellar velocity dispersion in radio-loud AGNs.

4 CONCLUSIONS

By estimating the black hole mass with the beaming effect eliminated, we have re-investigated the relationship between black hole mass and narrow [OIII] line width for a sample of 60 radio-loud and 63 radio-quiet AGNs compiled from the literature. Further, in order to know the influence of the radio emission on the narrow line region, the relationship between radio jet power and the narrow [OIII] width was also checked. The main conclusions can be summarized as follows:

- After eliminating the beaming effects in the optical luminosity and correcting the orientation effect in broad line widths, the $M_{\rm BH}$–$\sigma_{\rm [OIII]}$ relation in radio-loud AGNs still deviates from the same relation for nearby normal galaxies. On the other hand, it is re-confirmed that the radio-quiet AGNs follow the same $M_{\rm BH}$–σ_* relation as the nearby normal galaxies.
- We find there is no significant correlation between the radio jet power and the narrow [OIII] line width, indicating that there is no obvious interaction between radio jet and the narrow line region. The deviation of the $M_{\rm BH}$–σ_* relation of radio-loud AGNs cannot be explained by interaction between radio jets and the narrow line region.
- The deviation of the $M_{\rm BH}$–$\sigma_{\rm [OIII]}$ of radio-loud AGNs might not be caused by the uncertainty in the black hole mass calculation, indicating that the narrow [OIII] line width might not be a good indicator of the stellar velocity dispersion. Another possible explanation is that the radio-loud AGNs might not follow the same $M_{\rm BH}$–σ_* relation as normal galaxies and radio-quiet AGNs. Further investigations are needed.

Acknowledgements We are grateful to Xinwu Cao and Minfeng Gu for helpful discussions. We thank the anonymous referee for insightful comments and constructive suggestions. This work is supported by the NSFC under Grants 10373019, 10333020 and 10543002. This research has made use of the NASA/ IPAC Extragalactic Database (NED), which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

References

Bian W., Zhao Y., 2004, MNRAS, 347, 607
Bian W., Yuan Q. R., Zhao Y. H., 2005, MNRAS, 364, 187
Bonning E. W., Shields G. A., Salviander S. et al., 2005, ApJ, 626, 89
Boroson T. D., Green R. F., 1992, ApJS, 80, 109 (BG92)
Boroson T. A., 2003, ApJ, 585, 647
Brotherton M. S., 1996, ApJS, 102, 1 (B96)
Cao X. W., 2004, ApJ, 609, 80
Dahari O., Michael M., Robertis D., 1988, ApJS, 67, 249 (D88)
de Bruyn A. G., Wilson A. S., 1978, A&A, 64, 433
Ferrarese L., Merritt D., 2000, ApJ, 539, L9
Ferrarese L., Pogge R. W., Peterson B. M. et al., 2001, ApJ, 555, L79
Gebhardt K., Bender R., Bower G. et al., 2000a, ApJ, 539, L13
Gebhardt K., Kormendy J., Ho L. C. et al., 2000b, ApJ, 543, L5
Greene J. E., Ho L. C., 2005, ApJ, 627, 721
Heckman T. M., Milee G. K., Green R. F., 1984, ApJ, 281, 525 (H84)
Ho L. C., Peng C. Y., 2001, ApJ, 555, 650

Kaspi S., Smith P. S., Netzer H. et al., 2000, ApJ, 533, 631
Kellermann K. I., Pauliny-Toth I. I. K., Williams P. J. S., 1969, ApJ, 157, 1
Kormendy J., Richstone D., 1995, ARA&A, 33, 581 on Relativistic Astrophysics, eds. H. Martel & J. C. Wheeler, New York: AIP, p.363
Lacy M., Laurent-Muehleisen S. A., Ridgway S. E. et al., 2001, ApJ, 551, L17
Laor A., 2000, ApJ, 543, L111
Lawrence C. R., Zucker J. R., REanhead C. S. et al., 1996, ApJS, 107, 541 (L96)
Liu Y., Jiang D. R., Gu M. F., 2006, ApJ, 637, 669
Magorrian J., Tremaine S., Richstone D. et al., 1998, AJ, 115, 2285
Nelson C. H., Whittle M., 1995, ApJS, 99, 67
Nelson C. H., Whittle M., 1996, ApJ, 465, 96
Punsly B., 2005, ApJ, 623, L9
Salviander S., Shields G. A., Gebhardt K. et al., astro-ph/0601675
Sergeev S. G., Pronik V. I., Sergeeva E. A. et al., 1999, AJ, 118, 2658 (S99)
Shields G. A., Gebhardt K., Salviander S. et al., 2003, ApJ, 583, 124
Smith E. P., Heckman T. M., Illingworth G. D., 1990, ApJ, 356, 399
Steiner J. E., 1981, ApJ, 250, 469 (S81)
Sulentic J. W., 1989, ApJ, 343, 54 (S89b)
Tran H. D., 1995, ApJ, 440, 565 (T95)
Tremaine S., Gebhardt K., Bender R. et al., 2002, ApJ, 574, 740
Whittle M., 1992, ApJS, 79, 49 (W92a)
Wang T., Lu Y., 2001, A&A, 377, 52 (WL01)
Wu X. B., Wang R., Kong M. Z. et al., 2004, A&A, 424, 793
Xu C., Livio M., Baum S., 1999, AJ, 118, 1169
Xu Y., Cao X. W., 2006, Chin. J. Astron. Astrophys. (ChJAA), 6, 649